

# **Polarized Downwelling Radiance Distribution Camera System**

Kenneth J. Voss

Physics Department, University of Miami

Coral Gables, Fl. 33124

phone: (305) 284-2323 ext 2    fax: (305) 284-4222    email: [vooss@physics.miami.edu](mailto:vooss@physics.miami.edu)

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<http://optics.physics.miami.edu>

## **LONG-TERM GOALS**

My work involves experimentally investigating the interrelationships and variability of optical properties in the ocean and atmosphere. My goal is to define the variability of the optical properties, particularly those dealing with light scattering, and to improve the prediction capabilities of image and radiative transfer models used in the ocean. My near term ocean optics objectives have been: 1) to improve the measurement capability of measuring the in-water and above-water spectral radiance distribution and extending this capability to polarization, 2) to investigate the variability of the Point Spread Function (PSF) as it relates to the imaging properties of the ocean, and 3) to improve the characterization of the Bi-directional Reflectance Distribution Function (BRDF) of benthic surfaces in the ocean, and 4) to understand the capabilities and limitations of using radiative transfer to model the BRDF of particulate surfaces.

## **OBJECTIVES**

The major objective of this research was to build a camera system to measure the downwelling spectral polarized radiance distribution, in the near surface of the ocean.

## **APPROACH**

In this project we had to design and build a new polarization imaging camera system. This instrument follows in the footsteps of other instruments we have developed (Voss and Liu, 1997) and uses a combination of 3-4 images of the radiance distribution to form this polarized radiance distribution. Because the downwelling radiance distribution is very dynamic, the system needed to quickly make these images and have them as matched as possible required a completely new design.

## **WORK COMPLETED**

The system we have built uses 4 fisheye camera lenses with coherent fiber bundles behind each image. Behind each fisheye lens is a polarizer in a different orientation. The image of each fisheye lens is formed on a coherent fiber bundle that can transmit the image, with the various polarization states. It also has the feature of unpolarizing the images, to avoid problems with polarization sensitivity in the rest of the system. The bundles are then brought together and imaged on a CCD array camera, through a filter changer (for spectral information). Thus in a single image we have 4 separate fisheye images of the scene, each with different polarization information. A sample raw image is shown in Fig. 1.

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Figures 2 and 3 are pictures of the instrument as is. The filter changer in the system allows measurement of the spectral radiance distribution at 7 wavelengths.



**Figure 1.** Sample image from Polarization camera system. There are 4 separate fisheye images shown in this one camera image, the result of our quadfibrated fiber bundle. Each small fisheye image carries different polarization information. Three of the images have linear polarizers in line with the image optical path. The remaining image contains a circular polarization analyzer. By combining these images, the 4 stokes vectors can be determined.

To obtain the radiance distribution in real units, with the polarization information, requires extensive calibration and instrument characterization. The steps required are:

- 1) Flat field of coherent fiber bundle. The fiber bundle image has lines running through it due to absorbing layers that are put into the bundle to reduce fiber cross talk. In addition some fibers transmit better than others, so this step is necessary to improve the image quality and quantitative information.
- 2) Spectral calibration of system
- 3) Rolloff characterization of the lens system
- 4) Immersion calibration, to determine the difference in camera operation in-water vs in-air.
- 5) Angular calibration
- 6) Absolute calibration

Each of these calibration steps has been performed for this instrument. The instrument details, and the details of these calibration steps has been described in a paper submitted to the Ocean Optics XIX meeting.

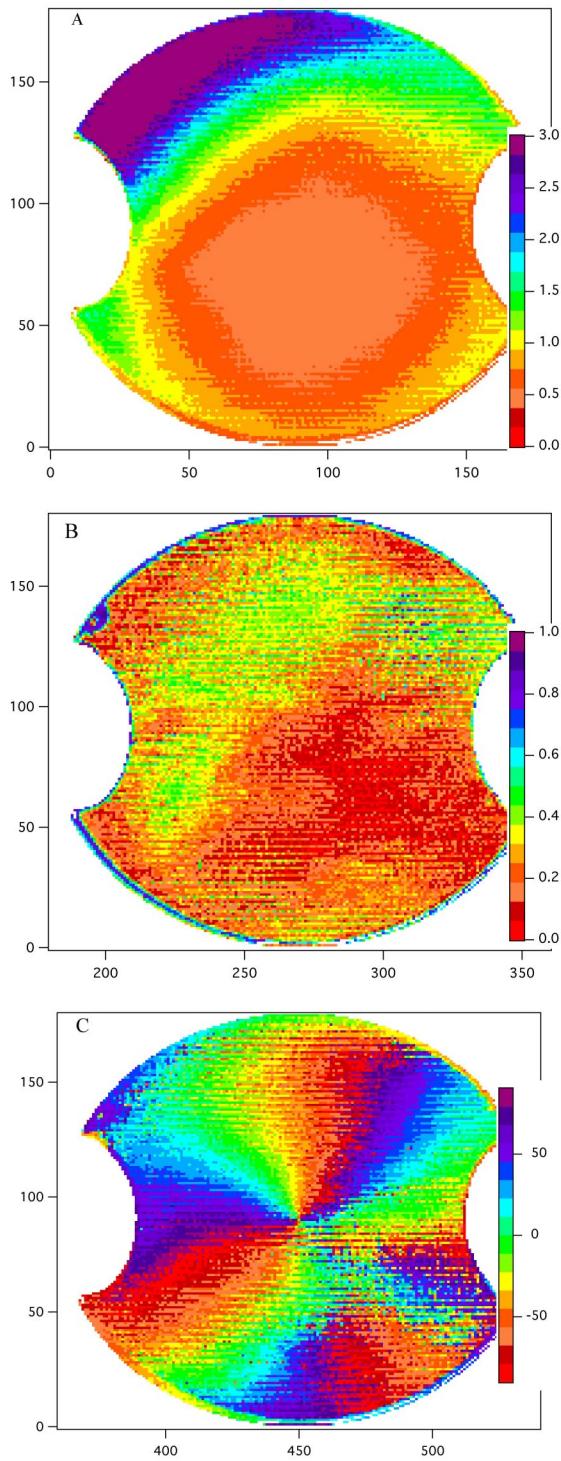
The instrument was built to be used for the ONR Radyo experiment. The first field test of the instrument was performed in January at Scripps Pier. The instrument worked well at this field test, however in terms of oceanographic data the presence of the pier, and the shallow water, was a strong influence on the data obtained. Our tests in San Diego showed us that it would be helpful to reduce the weight of the instrument. We have since torn the instrument apart, lightened the case, and are reassembling it now. It was just recently used in the RADYO field test in September in the Santa Barbara Channel.



*Figure 2. This is a picture of the interior of the polarization camera system. On the far left is the camera (the blue box), in front of which is the IFW filter chamber. The coherent fiber bundle is shown, with each leg going to fisheye lenses in the lower portion of the box. We also have a pressure transducer, tilt and roll indicator, and other associated electronics. The system is controlled by the laptop to the left of the picture.*



*Figure 3. Picture of the top of the polarization camera system. One can see the 4 fisheye lenses all aligned in a row. On the left are connectors to allow the system to be used, either over a dedicated cable (the big connector) or through the ROV system.*



**Figure 4.** This is an example upwelling image showing first intensity (relative units, Fig. A), Degree of polarization (1 = 100% polarized, Fig. B), and angle of polarization plane, C (zero corresponds to a plane of polarization perpendicular to the plane containing the view direction and nadir).

## **RESULTS**

We have only just now started to get field data with this instrument so there are no significant results to report at this time. The results during the Pier test mainly pointed out areas we needed to improve. The proximity of the pier, and the shallow water, made most of the data difficult or impossible to interpret. Figure 4 shows an example data set from the most recent cruise in the Santa Barbara Channel. This is an upwelling radiance distribution image, showing the intensity, degree of polarization and angle of the polarization plane. The image is shown in the fisheye projection, where the center of the circle is the nadir direction and angle from nadir is linearly proportional to the distance from the center of the image to the edge (which corresponds to 90 degree Nadir angle). The halfmoon shape out of each side corresponds to the image area for which the camera would be able to see a neighboring dome, so there is no data there.

From the intensity image one can see that the solar direction is towards the upper left of the images. The minimum upwelling radiance in this distribution is towards the anti-solar direction. Often in clear water this minimum is on the solar side of nadir, but with this higher Chl water, this isn't the case.

The degree of polarization image shows a degree of polarization which ranges from 0 to almost 50%. The maximum degree of polarization is in the region of 90 degree scattering. The angle of the polarization plane, chi, varies in a reasonable fashion around the azimuthal direction. The common definition has the reference plane containing the view direction and the nadir direction. 0 degrees in this coordinate system corresponds to a polarization plane perpendicular to this reference plane, and chi is 0 in the solar direction.

## **IMPACT/APPLICATIONS**

This system will provide a brand new measurement capability. In the RaDYo program this instrument will be used in combination with other measurements of the sea surface and optical parameters. The goal of the overall RadYO program is to understand how the radiance distribution is modified in the near surface, and what factors are important to this modification.

## **RELATED PROJECTS**

We will be using this instrument during the ONR RadYO program. Our work on the polarized radiance distribution is also related to our efforts with NASA funding to look at both the upwelling radiance distribution and the polarized upwelling radiance distribution.

## **REFERENCES**

K. J. Voss and Y. Liu, "Polarized radiance distribution measurements of skylight: I. system description and characterization", 1997, Applied Optics, **36**: 6083-6094.